# Compact Circular Polarized Antenna Design with H-Shaped Slots and Stair Notches for Wireless LAN Application of 2.4 GHz

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***Abstract*— This paper presents the design of a circular polarized antenna for wireless communication system. Firstly, the linear polarization antenna is simulated in the CST Microwave Studio. This linear polarization antenna is designed by using double H-shaped slots, coplanar waveguide (CPW) and stair notches at the patch techniques. Then, the truncated corners at the patch are designed to create a circular polarization antenna. The dimension of this circular polarization antenna is 28 mm width x 33 mm length. Both antennas are designed for a single frequency operation band at 2.4 GHz. The return-loss performance of the circular polarized antenna is - 46.785 dB and – 39.758 dB for each simulation and measurement respectively**

***Index Terms*— Wireless LAN, patch antenna, circular polarized, stair notches**

## I. Introduction

Antenna plays a crucial role in the field of telecommunication namely for satellite communication, mobile phone and military use [1]. The growth of mobile communications results in the increasing demand of smart phones, wireless Internet and other broadband applications. In relation to this, there is an increasing demand for high data rate and high capacity to satisfy the growth of mobile communications [2-3]. Further, the advantage of wireless technology such as wireless local area network (WLAN) is well known to provide more speed and range within the network. Studies, such as those reported in [4-6] have developed many antenna designs for WLAN applications.

In the modern wireless communication, products such as smartphones and radio frequency identification (RFID) tags are purposely designed to be lightweight and very compact in size so that they are portable and easy to be used everywhere. For instance, an antenna is designed in a very small size so that the antenna is able to fit inside compact-sized products. Moreover, wireless devices are designed to be portable so that they fit into small devices and used practically. Thus, the size of an antenna is also one of the main criteria to be taken into account when designing antennas [7-9].

The use of linear polarization (LP) provides bad results to any signals since they are not straight and detect signal in one direction only, causing a lost of signal strength. This difficulty can be reduced by Circular polarization (CP) that always receives a component of a signal, and this allows it to have an angular variation. Circular polarization antennas are able to send and receive signals in all angles, thus limiting the transition of the signal strength to a specific plane resulting it to be utilized. Works related to circular polarization antenna have been documented in [10-12].

This paper shows a compact circular polarized antenna by using H-shape slots for the wireless LAN applications. An example of antenna design that applies an H-slot in a design has been done by [13]. The important parameters for this antenna are the resonant frequency, return loss, gain, and radiation pattern.

## II. Antenna design

Microstrip patch antennas consist of a metal patch suspended over a ground plane. Dielectric substrates like FR-or Roger RT/Duroid 5880 are the important layers that affect the performance of the patch antenna.

In this work, the antennas are designed for the frequency of 2.4 GHz, which is useful for the WLAN application. The 2.4 GHz frequency is an unlicensed band and is free for the use of the public. The antenna is simulated using FR-4 board and copper. FR-4 board with the thickness of 1.6 mm, tangent loss of 0.019 S/m and permittivity of 4.4 are used in designing the antenna whereas the copper with the thickness of 0.035 mm is used as the conductor. The specification of the design is listed in Table 1.

The design of the antenna is targeted to have gains ranging from 2 dB to 4 dB. Meanwhile, the axial ratio for a circular polarization antenna must be below - 2.5 dB. Prior to this, the antenna is designed to fulfill the compact issue in terms of its size by using coplanar waveguide (CPW) feed structure.

There are two antenna designs presented in this paper. The first design is for the linear polarization antenna, while the second design is for the circular polarization antenna. First, the linear polarization antenna is designed based on a rectangular patch structure. Then, the patch is added with double H-shaped slots and finally, the return-loss of the design is improved by adding a stair notch to the patch.

Table 1
Specification of the antenna design

| Specification | Value |
|---|---|
| Frequency | 2.4 GHz |
| Return-loss | < -10 dB |
| Gain | 2 dB to 4 dB |
| Radiation efficiency | < - 3 dB |
| Total efficiency | < - 3 dB |
| Multipolarization | Circular polarization |
| Axial ratio | < 2.5 for circular polarization |

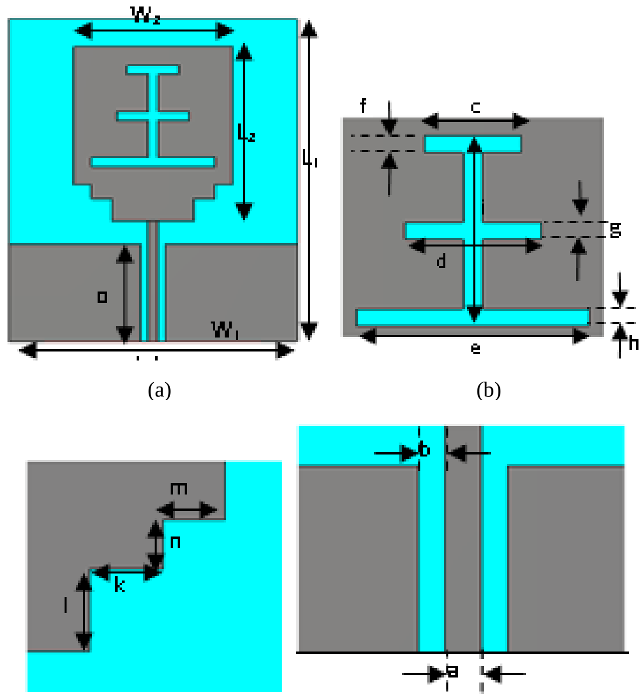



Figure 1: Front-view design of the linear polarization antenna, (a) double H-shaped slots, (b) patch antenna, (c) stair notches, (d) feedline

Figure 1 shows the schematic diagram and the dimensions of the linear polarization antenna. Table 2 displays the optimum dimension of the linear polarization antenna after the parametric study involving different dimensions of different slot lengths labeled as **f**, **g** and **h**, the stair notches lengths represented by **l**, **k**, **m**, **n** and the patch width/lengths represented by $\mathbf{L_2}$ and $\mathbf{W_2}$. This antenna has a width and length of 15.4 mm and 19 mm respectively.

Table 2
Optimum dimension of linear polarized antenna

| Parameter | Value (mm) |
|---|---|
| $L_2$ | 19 |
| $W_2$ | 15.4 |
| d | 7 |
| e | 12 |
| f | 1 |
| g | 1 |
| h | 1 |
| i | 11 |
| j | 1 |
| k | 3.7 |
| l | 2.5 |
| m | 1.7 |
| n | 1.5 |
| o | 10.5 |

Figure 2 shows the configuration of the circular polarization antenna (front view). The antenna that consists of a rectangular patch with double H-shaped slots and stair notches on top of the patch is the same as the linear polarization antenna. The only difference is that in its design; the patch is cut out with a truncated corner to create a circular polarization radiation. For further illustration, Table 3 represents the optimum dimensions of the circular polarization antenna. In this case, the parametric study is conducted by changing the truncated corner width dimension **E**, **A** and **B** symbol and the width and length of the substrate with 28 mm and 33 mm, respectively. The coplanar waveguide (CPW) length, **F** is 7 mm.

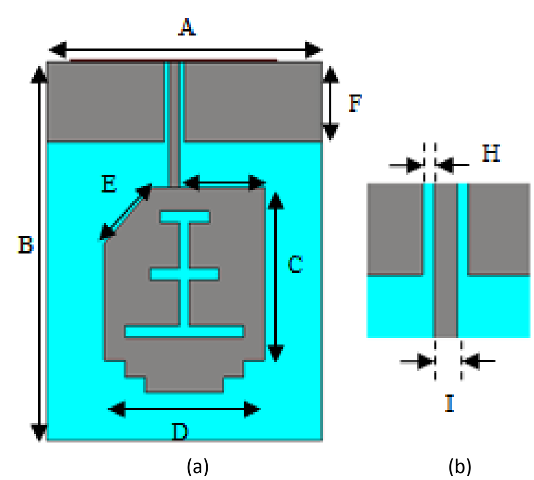



Figure 2: Front view design of final circular polarization antenna, (a) Front view of the patch antenna with H-shaped slot, (b) Feed line with coplanar waveguide (CPW) position at patch antenna

Table 3
Parameter of the circular antenna

| Parameter | Value (mm) |
|---|---|
| A | 28 |
| B | 33 |
| C | 17.9 |
| D | 16.26 |
| E | 6.88 |
| F | 7 |
| G | 8.63 |
| H | 0.5 |
| J | 1 |

## III. Result

Figure 3 presents the comparison of return-loss between the simulation and measurement of the linear polarization antenna. The return-loss of the linear polarization antenna is – 66.358 dB at 2.401 GHz for simulation while – 37.33 dB at 2.386 GHz for measurement.

After the process of the parametric study is done, the width and length of the H-shaped slots can shift the resonant frequency to the left side. For instance, the three striped slots in this case can reduce more resonant frequency, as compared to using one striped slot or two striped slots. Prior to this, the bandwidth of the antenna is improved when the height of the ground plane, labelled as **F**, is increased.

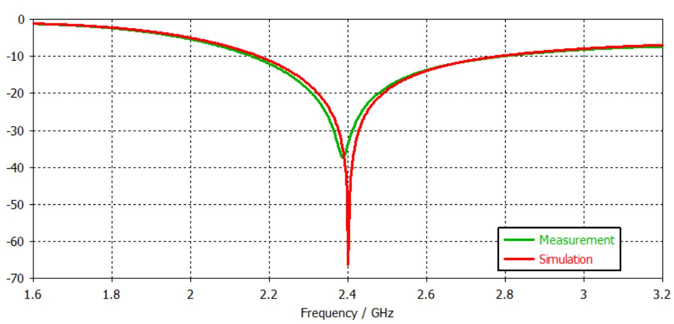



Figure 3: Return loss comparison for simulation and measurement for linear polarization antenna

Figure 4 and Table 4 show the return-loss of the circular polarization antenna. The frequency resonant for the measurement is shifted to the left compared to the simulation result. The bandwidth of the measured response is wider than the simulation result. For the simulation results, this antenna has the resonant frequency at 2.401 GHz with a return-loss of - 46.785 dB, while the measurement shows the resonant at 2.391 GHz with a return-loss of – 39.758 dB. There is a small ripple that occurs in the measurement result, which is due to the connection of the equipment and the cable. However, the bandwidth of the simulation is wider than the measurement result, which is 500 MHz for the simulation result and only 46 MHz for the measurement.

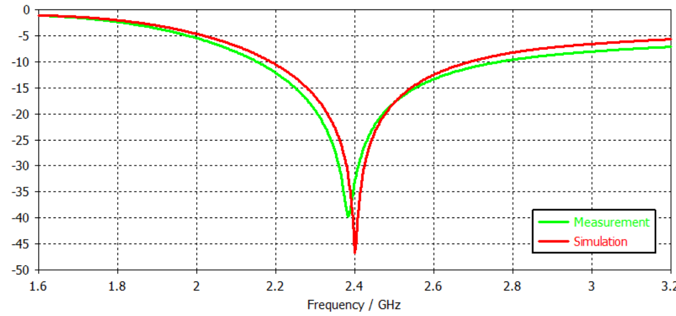



Figure 4: Return-loss comparison for simulation and measurement for circular polarization antenna

Table 4
Comparison of simulation result and measurement for circular polarization

| Parameters | Simulation | Measurement |
|---|---|---|
| Frequency (GHz) | 2.401 | 2.391 |
| Return-loss (dB) | - 46.785 | - 39.758 |
| Radiation Efficiency (dB) | -1.858 | - |
| Total Efficiency (dB) | -1.859 | - |
| Axial Ratio (dB) | 0.4035 | - |
| Directivity (dBi) | 1.964 | - |
| Gain | 1.052 | 1.312 |

The circular polarized antenna shows that the stair notches can improve the return-loss performance at the desired frequency. In contrast, the increment of H-shaped slots with width, **f**, **g** and **h** will shift the resonant frequency to the left side. In addition, the width of the feedline, **I** and **a,** for both linear and circular polarization antenna, will determine the antenna input impedance. This means that the 50 ohm input impedance is chosen for both designs in order to achieve a better efficiency performance.

Moving on, Figure 5 examines the axial ratio of the circular polarization antenna. The simulation result for axial ratio at 2.4 GHz is marked at 0.4035 dB. Therefore, this design can resonate at 2.4 GHz with circular polarization radiation. Other than that, the axial ratio of this design is higher than 3 dB in between 2.75 GHz to 2.97 GHz, which means that the design is having a linear polarization at this range. Besides that, with the increment of the truncated corner width, **E** until 6.88 mm, the axial ratio and the return-loss of the design can be improved.

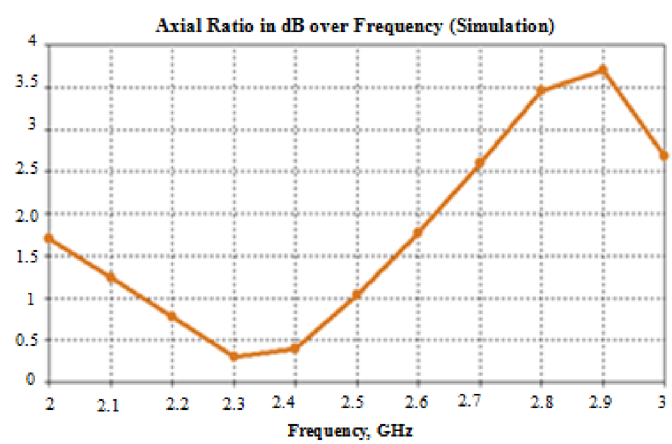
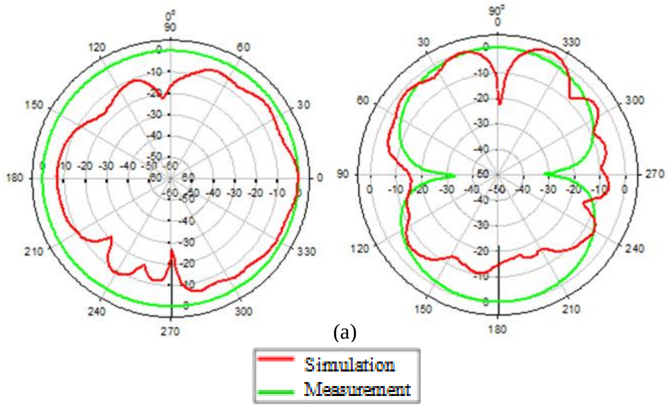
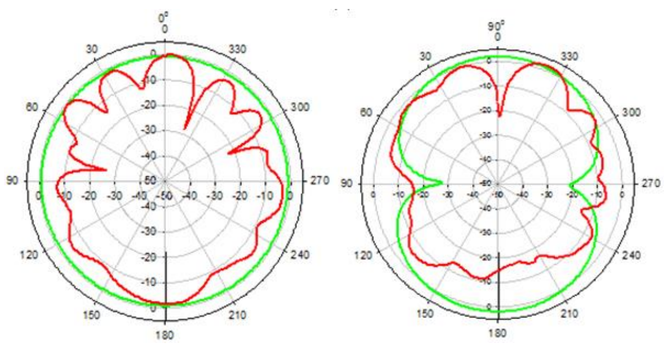



Figure 5: Axial ratio of circular polarized antenna

A comparison of the radiation pattern between the simulation and the measurement for the circular polarization antenna is shown in Figure 6. The radiation pattern of the simulation in the vertical orientation is resembled by an '8' shape. In contrast, the measured radiation pattern is shown in the shape of a circle. The similar circle also can be seen for the radiation pattern in the horizontal orientation.



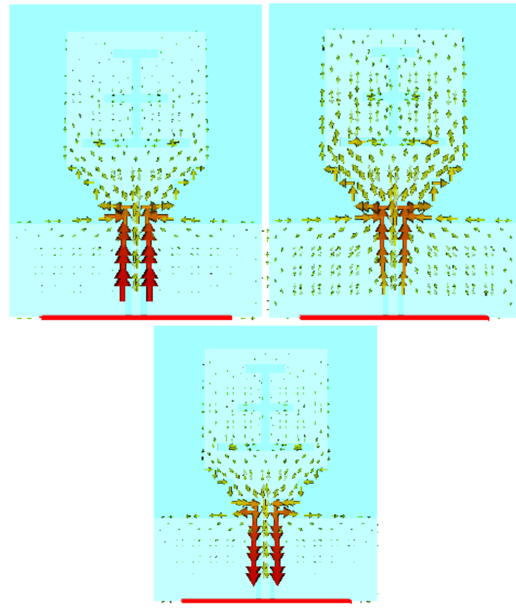

(a)



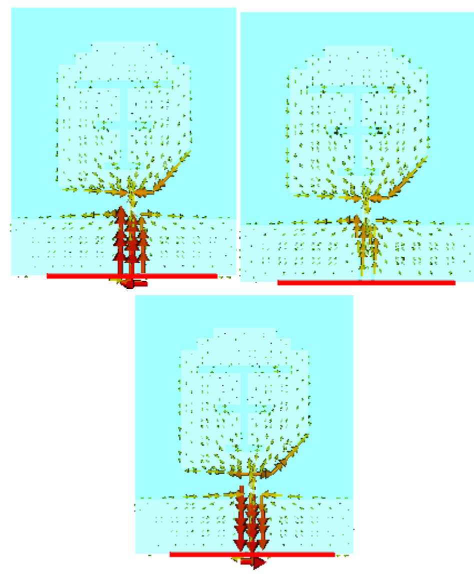
(b)

Figure 6: Radiation pattern comparisons, simulation (green) and measurement (red), (a) linear polarization, $0^0$ and $90^0$, (b) circular polarization, $0^0$ and $90^0$

Lastly, Figure 7 depicts the current surfaces of the linear and circular polarization antennas at three different current phases. The figure shows that both antennas have high current density at the feedline structure at the frequency of 2.4 GHz. There are also high current densities found at the stair notches' structures of **l, k, m, n** for the linear polarization antenna. In contrast, the high current density can be seen at the truncated corner, **E** for the circular polarization antenna. A shown in Figure 7, the linear polarization antenna shows the up-down arrow and left-right arrow, while the circular polarization antenna shows the additional arrow type of rotating style.



(a)



(b)

Figure 7: Surface current distribution for the antenna, (a) at the linear polarization antenna, current phase = $0^0$, $90^0$ and $180^0$, (b) at the circular polarization, current phase = $0^0$, $90^0$ and $180^0$

Figure 8 shows the 3D gain of the circular polarization antenna. The gain of this antenna is 1.052 dB for simulation and 1.312 dB for measurement. At 2 GHz, the gain of the antenna is only 0.75 dB, but it had increased at a higher frequency such as 1.129 dB at 3 GHz. Figure 9 shows the gain of circular polarized antenna over frequency.

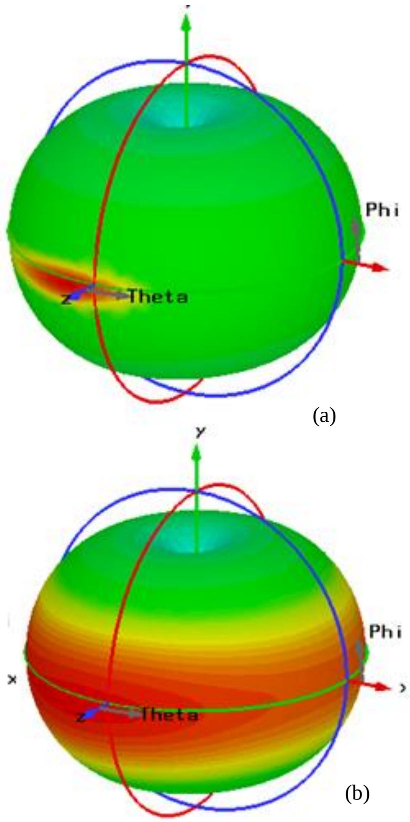



Figure 8: 3DGain and directivity for circular polarization antenna, (a) gain, (b) directivity

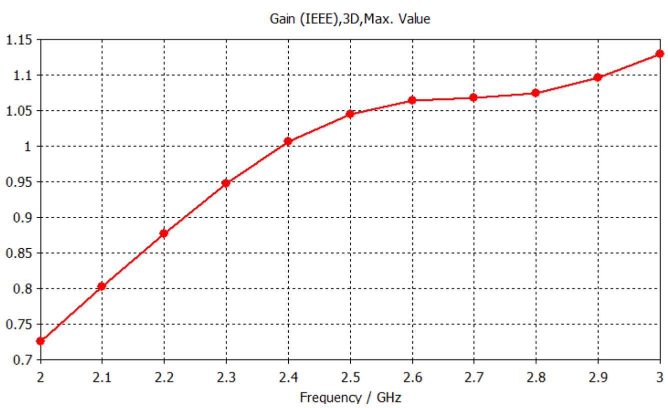



Figure 9: Gain of circular polarized antenna over frequency

## IV. CONCLUSION

A circular polarization antenna designed using truncated corner, coplanar waveguide, stair notches and H-shaped slot is proposed to have a frequency of 2.4 GHz while the return-loss performance is marked at having – 31.78 dB and bandwidth of 46 MHz. The axial ratio for the circular polarized antenna is 0.0435 dB with the same frequency of 2.4 GHz. Based on the explanations, this antenna design can be used to perform polarization diversity in the wireless system. Therfore, the achievement in this work is to create dual polarization antenna type of linear and circular.

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## REFERENCES

[1] Chang, L. C., Tsai, C. H., Hsu P., Liu, C. C., "A Polarization diversity MIMO antenna design for WiMAX dongle application", 2010 Asia-Pacific Microwave Conference Proceedings (APMC), pp. 762-765, Dec. 2010.
[2] Vergerio, S., Rossi, J-P., Sabouroux, P., "A two PIFA antenna systems for mobile phone at 2GHz with MIMO applications", European Conference on Antennas and Propagation (EuCAP 2006), pp. 1-5, Nov. 2006.
[3] Elliot, P. G., Rosario, E. N., Davis, R. J., Rzhanov, A. E., "MIMO polarization diversity antenna with ultra-wide bandwidth and small size", IEEE International Symposium Phased Array Systems and Technology (ARRAY), 2010, pp. 559-566, Oct. 2010.
[4] Nurul, H. M. R., Soh, P. J., Azremi, A. A. H., Saidatul, N. A., Norra, S. R., Ibrahim, M. I., Ahmad, R. B., "A Dual Band Planar Monopole Antenna with Inverted-M Parasitic Plane," 2007 Asia-Pacific Conference on Applied Electromagnetics Proceedings (APACE 2007), pp. 1-4, 2007
[5] Daniati, N., Nusantara, H., Munir, A., "G-Patch Dualband Printed Monopole Atenna for GPS and WLAN Application," 2012 7th nternational Conference on Telecommunication Systems, Services and Applications, pp. 237-240,2012
[6] Lotfi, P., Azarmanesh, M., Soltani, S., "Rotatable Dual Band-Notched UWB/Triple-Band WLAN Reconfigurable Antenna," IEEE Antennas and Wireless Propagation Letters, vol. 12,pp. 104-107,2013
[7] Lu, Y. C., Wu, Y. S., Chiu C. T., Lin, Y. C., "A novel compact design of USB dongle antenna for bluetooth applications", IEEE Radio and Wireless Symposium (RWS'09), pp. 31-34, Jan. 2009.
[8] Lee, C. J., Gummalla, A., Achour, M., "Compact dualband antenna subsystem for MIMO application", 2009 IEEE International Workshop Antenna Technology (iWAT 2009), pp. 1-4, March 2009.
[9] Liu, X. F., Chen, Y. B., Jiao, Y. C., Zhang, F. S., "Design and optimization of a compact patch antenna", International Conference on Material and Manufacturing Technology (ICMMT'07), pp. 1-3, April 2007.
[10] U. Singh and M. Rattan, "Design of linear and circular antenna arrays using cuckoo optimization algorithm," Progress In Electromagnetics Research C, Vol. 46, 1-11, 2014.
[11] M. Barbuto, F. Trotta, F. Bilotti, and A. Toscano, "Circular polarized patch antenna generating orbital angular momentum," Progress In Electromagnetics Research, Vol. 148, 23-30, 2014.
[12] J. Wu, H. Yang, and Y.-Z. Yin, "Dual circularly polarized antenna with suspended strip line feeding," Progress In Electromagnetics Research C, Vol. 55, 9-16, 2014.
[13] Islam, M. T., Shakib, M. N., Misran, N., "Broadband E-H Shaped Microstrip Patch Antenna for Wireless Systems," Progress In Electromagnetics Research, PIER 98, pp. 163-173, 2009.